Coordination for Effective Performance During Crises When Training Matters

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Coordination for Effective Performance During Crises When Training Matters

Abstract

This paper examines what types of organizational structures are most effective during crisis, and least affected by crisis, as the level of training with the organization is varied. Many organizations are engaged in quasi-repetitive integrated decision making tasks in which similar problems occur one after the next but each problem is so complex that no one individual can access or analyze all pertinent information. In such organizations, training is vital as performance improves as individual decision makers gain experience. Regardless of the level of training, crises are expected to degrade performance. The degree to which performance is degraded, however, is expected to vary with the type of crisis, the level of training, and the type of organizational structure. Using simulation, the relative impact of crisis on organizations with different structures and different levels of training is examined. These studies demonstrate that the optimal crisis configuration depends on the level of training (Carley, minga; Carley, 1990a). One result is that dual-command hierarchies may fair best when the organization is fully trained, but in an untrained organization team structure may be more optimal.

Keywords:

- Organizational learning
- Training
- Crisis
- Communication Breakdowns
- Simulation

Coordination for Effective Performance During Crises When Training Matters

1. Introduction

Although organizations are beset by crises at various points, few organizations continually face crises. Crises may degrade organizational performance and often result in huge losses both to the organization and its environment. Effective performance during crisis can mitigate these losses. Consequently it is important to understand how to design (or structure) organizations so that they respond effectively when a crisis does occur. An organization designed for optimal crisis performance, however, may be disfunctional on a daily basis under normal operating conditions.

Design, however, is not the only factor affecting crisis level performance. Practioners argue the value of training for crisis. That is, they argue that since crises are relatively rare performance during crises can be improved by prior training. Such training is expected to reduce stress on individual decision makers, and reduce the number of last minute decisions that need to be made. A well trained organization is expected to perform better during the crisis than a less fully trained organization. Whether training can makeup for poor design, or good design make up for lack of training, has not been addressed.

This paper uses simulation to examine the question — "what organizational structures are most effective during both crisis and normal operating conditions regardless of the level of training?" A model of organizational decision making is presented where: (1) the organization is faced with a continuous sequence of highly similar but not identical problems; (2) each problem is so complex that no one person has access to all of the information, rather the information is distributed across personnel; (3) the individual decision makers base their decisions on their own previous experience; (4) the individual decision makers have the ability to learn; and (5) the organization's decision is generated by combining the decisions made (not the information held) by the individual decision makers. This model draws on elements of garbage can or organized anarchy theory (March and Romelaer, 1976; Cohen, March and Olsen, 1972; Padgett, 1980a; Carley, 1986a), individual decision theory (Tversky and Kahneman, 1971; Tversky and Kahneman, 1974; Lichtenstein and Fischhoff, 1977), and work in distributed decision making (Smith, 1980; Davis, 1980; Durfee, Lesser and Corkill, 1985; Lesser and Corkill, 1981; Carley, mingb). Using simulation the ability of organizations with different coordination structures and different levels of training to cope with different types of communication breakdowns is examined. By contrasting different organizational structures and different causes of, and potential cures for, communication breakdowns it is possible to gain insight into what organizational designs are most effective.

Simulation is a particularly useful technique in this area as it enables the researcher to examine a wide range of variables and their inter-relationships in an area where real data is rare and difficult to obtain. Formal models of organizations, analyzed mathematically or via simulation,

have provided a great deal of insight into the effectiveness of various organizational designs (Cohen, March and Olsen, 1972; Padgett, 1980a; Carley, 1986b; Malone, 1987; Masuch and LaPotin, 1989; Carley, 1990b, for example). Further, many aspects of crises are amenable to being studied in this fashion.

The model presented, is an extension of an earlier model in which organizations are viewed as adaptive systems whose performance is dependent on the integrated performance of the individual decision makers in the organization who themselves learn from experience (Carley, mingb; Carley, 1990b). As noted in (Carley, mingb) this model is based on the recognition that: organizational behavior is historically based (Lindblom, 1959; Steinbruner, 1974; Levitt and March, 1988); organizational learning depends, at least in part, on the cognitive abilities (memories, decision making capability, learning capability, and so on) of individual decision makers within the organization (Hastie, 1984; Johnson and Hasher, 1987); organizations are disorderly, in part due to communication breakdowns, with the upshot that different decision makers may take part in each decision (March and Romelaer, 1976; Cohen, March and Olsen, 1972; Padgett, 1980a); and, finally, organizations under normal operating conditions are typically faced with a sequence of highly similar, but rarely identical, problems that are so complex that no one decision maker in the organization may be able to cope with, let alone have access to, all of the information needed to make a decision. I will refer to sets of problems with these characteristics as quasi-repetitive integrated decision making tasks.

When crises occur, many organizations are doing what they are trained to do, but the particular anomalies of the crisis period makes the specific problem with which the organization faced different from those with which it had previous experience. In order to examine this type of behavior a new type of task is defined — the quasi-repetitive integrated decision making tasks. A task is quasi-repetitive if the same basic type of problem is faced over and over again but some of the information, constraints, parameters, etc. are different each decision period, thus producing slightly different decisions. Quasi-repetitiveness can be thought of as a continuous scale bounded on one end by repetitive tasks and the other by non-repetitive tasks. A task would be repetitive if exactly the same problem is faced over and over again; whereas, a task is non-repetitive if the problem is unique. Crises by their vary nature may be on the less repetitive end of the spectrum. A task is said to be integrated if the final organizational decision is determined by somehow integrating into a single decision a plethora of previous smaller or component decisions made by various decision making units (DMUs)[1] within the organization. Such quasi-repetitive integrated decision making tasks are quite common in the organizational arena. At a very general level such tasks include determining whether the positive implications of a possible policy outweigh the negative implications (e.g. determining for a new line of research or a new product whether the chances for success outweigh the chances for failure). At a more specific level, tasks with these characteristics

[1]A decision making unit, DMU, can be a person, an algorithm, or a collection of people and algorithms.

include air traffic control (Steeb, 1980; Thorndyke, 1981; LaPorte and Consolini, 1988), sensor data interpretation (Smith, 1980), and planning and budgeting (Crecine, 1986; Padgett, 1980b). Despite the prevalence of such tasks in organizations, the ability of the organization to learn when faced with a quasi-repetitive integrated decision making task has not been explored analytically. Nor has there been an analytic exploration of the effect of communication breakdowns on performance when the organization is faced with such quasi-repetitive integrated decision making tasks.

This study suggests that it is generally not possible for the organization to learn to always make the right decision, especially as information necessary to guarantee the right decision may not be available at the time the decision must be made. In point of fact, in major organizations wrong decisions do result from such communication breakdowns. The situation, however, is not hopeless. The organization can structure itself to maximize the number of "best decisions" (decisions that are right given the currently available information). The model suggests a series of possible changes that can be made in the organization in order to increase the likelihood that the best decision is made. These include, but are not limited to, decreasing the rate of personnel turnover or transfer and increasing job specialization. Not all of these options are available to any particular upper-level manager.

2. Communication Breakdown Model

2.1. Characterizing the Situation

Organizations are viewed from a distributed decision making framework; i.e., organizations are engaged in a quasi-repetitive integrated decision making task. Organizational life is divided into a sequence of decision periods. Each decision period (see figure 1), the organization is faced with a problem that is similar but not identical to one that it has faced before, and the problem is so complicated that it can only be "solved" by a large number of personnel, working in different locations and with access to different information. During each period the following four events occur: (1) personnel gather information, (2) decisions are made, (3) decisions are communicated and integrated, and (4) feedback on the "correctness" of the decision is provided. Crises can disrupt this process in a variety of ways; e.g., by increasing the amount of incoming information, decreasing the reliability of information, changing which personnel are available to gather information and make decisions, making certain communication channels unavailable, and eliminating or decreasing the accuracy of feedback.

The organization operates across a sequence of decision making periods. In each decision period the organization faces a new problem that is similar, but not identical, to previous problems. During each period, information related to the new problem is evaluated, a decision is made, and the members of the organization are informed of the "correctness" of their decision for that problem. This operational procedure is followed both during periods of crisis and during periods of non-crisis. During periods of crisis the incoming information may be incomplete or wrong resulting in erroneous

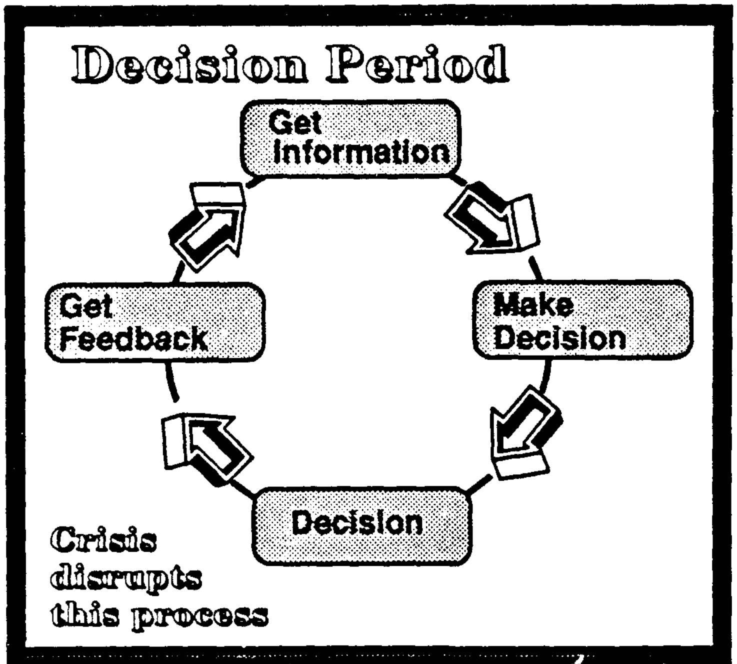


Figure 1: Organizational Life

decisions and there may be communication breakdowns which inhibit the flow of decisions and feedback on those decisions. Portions of this model, specifically those related to task description, the description of the centralized hierarchical structures, and the description of the team structure previously appeared in (Carley, mingb; Carley, 1990b).

2.2. Coordination Scheme

Each organization has a coordination structure. In essence the coordination structure of an organization is its C^3I structure. In this paper, the coordination scheme is characterized by the organizational structure (who commands/communicates to whom and procedure for producing a final organizational decision) (see figure 2) and the access structure (who who has access to what information and hence the level of information redundancy) (see figure 3).

2.2.1. Organizational Structure

Typical command/communication structures examined are the centralized hierarchy (top of figure 2), the dual-command hierarchy (middle of figure 2), and the distributed team (bottom of figure 2). Analysts or field personnel are represented as lightly shaded circles, AEOs (or lieutenant commander) as darkly shaded circles, and the CEO (or commander) as a black circle. In all three types of organization each analyst sees a portion of the problem and makes a decision. In the centralized hierarchy and the dual-command hierarchy this decision is passed to the AEO who then makes a decision which is passed to the CEO who makes the final decision for the organization. Thus, in the hierarchies, institutional memory is centralized in the upper management, albeit in a reduced information form. In the distributed team, the analyst's decision is his "vote" as to what the final decision should be. In the distributed team the majority vote is the final decision. In the distributed team institutional memory is completely distributed. In all cases it is only the analysts who have access to the "raw data" associated with the problem. Thus, the organization is faced with

a sequence of problems and is composed of a set of decision makers each of whom has access to information and must generate a decision on some aspect of the decision. The organizational decision is generated by combining these individual decisions.

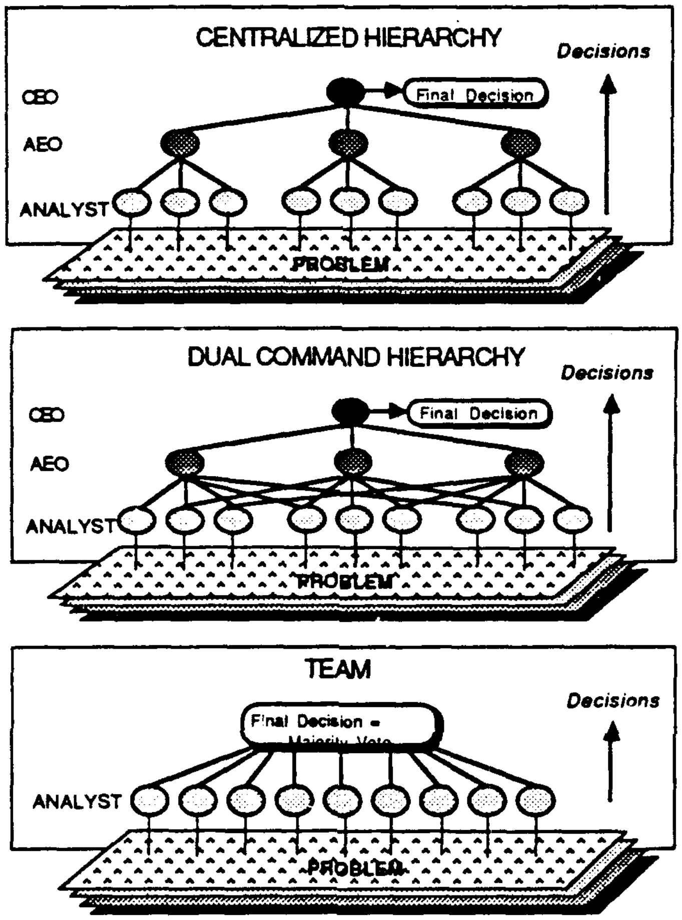


Figure 2: Typical Command/Communication Structures

Three organizational structures are examined: the centralized hierarchy (top), the dual command hierarchy (middle), and the team (bottom) (see figure 2). Analysts are represented as lightly shaded circles, AEOs as darkly shaded circles, and the CEO as a black circle. In all three types of organization each analyst sees a portion of the problem and makes a decision. The primary difference between the team and the hierarchical structures (centralized hierarchy and dual command hierarchy) is the presence of upper level management in the hierarchies and the absence of such management in the team. The presence of such upper level management, by mediating the decisions made by the analysts, may potentially reduce the impact of communication breakdowns by providing personnel who have a historical image of the entire structure and an ability to integrate lower level decisions. The primary difference between the centralized hierarchy and the dual command hierarchy is the presence of multiple paths by which information can reach management in the dual command hierarchy and only a single such path in the centralized hierarchy. The presence of multiple paths may potentially reduce the impact of communication breakdowns by

reducing the likelihood that some information will be completely lost. These structures are not meant to exhaust the set of potential or actual organizational structures. Rather, they represent idealized structural types that are interesting due to their prevalence in real organizations and that may be differentially affected by communication breakdowns. In addition, both the hierarchy (Weber, 1922; Burns and Stalker, 1961; Padgett, 1980a; Carley, 1986a, Malone, 1986; Malone, 1987) and the team (Cohen, March and Olsen, 1972; Marschak, 1955; Arrow and Radner, 1979; Radner, 1987; Gloves and Ledyard, 1977; Tsitsiklis and Athans, 1984; Strand, 1971; Bar-Shalom and Tse, 1973) have been extensively studied, but their performance has rarely been contrasted. The dual command hierarchy, such as that employed in the materiel acquisition process by the Army, has rarely been studied although in certain ways it is similar to the matrix structure (Davis and Lawrence, 1977). These three structures represent different points on the organizational spectrum in terms of the degree to which institutional memory and command is centralized.

Centralized Hierarchy: The centralized hierarchy is modeled as a three tier organization composed of a chief executive officer (CEO), a set of assistant executive officers (AEOs), and set of analysts. Each analyst in each decision period receives information (a subproblem), makes a decision (yes or no), and sends this decision to his or her AEO. The AEO takes the analysts' decisions, makes an integrated decision (yes or no), and sends this decision to the CEO. The CEO takes the AEOs' decisions, makes the final integrated decision (yes or no), finds out if it is correct, and then informs each AEO of the correct final decision. Then each AEO informs each analyst of the correct final decision. It is from these decisions and the resultant feedback that the analysts' experiences are formed. In this paper, the specific centralized hierarchy examined has 13 DMUs with 3 under each "manager" or "executive" as in figure 2. There are 9 analysts. A hierarchy of 13 DMUs is the minimum non-trivial hierarchy that can be examined such that the hierarchy has 3 levels and an odd number of DMUs under each "manager".

Dual Command Hierarchy: The dual command hierarchy, like the centralized hierarchy, is modeled as a three tier organization composed of a chief executive officer (CEO), a set of assistant executive officers (AEOs), and set of analysts. Each analyst in each decision period receives information (a subproblem), makes a decision (yes or no), and sends this decision to his or her AEO. In addition some analysts also send their decisions to another AEO who is listed as interested in the project. The AEO takes the analysts' decisions, makes an integrated decision (yes or no), and sends this decision to the CEO. The CEO takes the AEOs' decisions, makes the final integrated decision (yes or no), finds out if it is correct, and then informs each AEO of the correct final decision. Then each AEO informs each analyst from which they receive information of the correct final decision. It is from these decisions and the resultant feedback that the analysts' experiences are formed. In this paper, the specific dual command hierarchy examined has 13 DMUs with 3 under each "manager" or "executive" as in figure 2. There are 9 analysts. For each AEO one analyst reports only to him or her, and the other two analysts each also report to one other AEO. This size of organization is chosen so that it matches the hierarchy.

Team: The team is modeled as a single tier organization composed of a set of analysts. In each decision period, each analyst receives information (a subproblem), and makes a decision (yes or no) independent of the other analysts. The organization's decision (the final decision) is the majority vote of the analysts. The analysts then find out the correct decision. In this paper, the specific team analyzed has 9 DMUs all of which are analysts as in figure 2. The team has 9 DMUs in order to match the number of analysts in the hierarchy. The number of analysts, rather than total DMUs, is matched so that the complexity of the subproblem seen by each analyst is identical for the team and hierarchy for the same size problem while maintaining no overlap in the subproblems seen by the different analysts.

2.2.2. Information Access Structure

Which analyst knows which pieces of information, and hence the level of redundancy, is defined by the information access structure. In this paper three distinct access structures are examined: (1) segregated (left of figure 3), (2) triplely redundant (center of figure 3), (3) distributed (right of figure 3). Each of these access structures determines which analyst sees which portion of the problem and how much of the problem. These three access structures are chosen as they represent idealized forms of information access. In the segregated structure there is no information overlap, i.e., each piece of information is gathered by only one analyst. Whereas, in the other two structures each piece of information is known by multiple analysts. In the triplely redundant structure all of analysts under one AEO share the same information and there is no information sharing across AEOs; whereas, in the distributed structure each AEO has indirect access to all of the information known by any other AEO but his or her analysts each know a different set of information. The triplely redundant structure corresponds to each division having access to totally different information but all members of a division knowing the same thing; whereas the distributed structure corresponds to each division having access to the same information but from totally different perspectives.

Segregated: In the segregated access structure each analyst has access to a unique set of information; that is. there is no redundancy. In this case, should anything compromise an analyst — communication breakdown or incorrect information — the organization as a whole loses information and so may not be able to make the correct decision. This is implemented by giving each analyst access to a unique set of 3 bits. Since the task is composed of 27 bits and there are 9 analysts regardless of organizational structure, giving 3 bits to each analyst results in no redundancy (see figure 3).

Triplely Redundant: In the triplely redundant access structure three analysts share identical information. In this case, should anything compromise an analyst the organization does not lose information and there are two other analysts who will report to management or vote in exactly the same way. This is implemented by giving each analyst access to 9 bits of information; which in the hierarchies means that all analysts under one AEO have exactly the same information (see figure 3).

Distributed: In the distributed access structure the information that would be known by only one analyst in the segregated structure is in the distributed structure known not only by that analyst but is also distributed so that each piece is also known by two other analysts. Like the triplely redundant system each piece of information is known by 3 analysts; but, unlike the triplely redundant system no two analysts (let alone three) have access to exactly the same information. Consequently, two analysts who share some information may still make different decisions as they also do not share some information. In this case, should anything compromise an analyst the organization does not lose information but it might lose some of the value of that information. This is implemented by giving each analyst access to 9 bits of information 6 of which are also known by 6 other analysts (see figure 3).

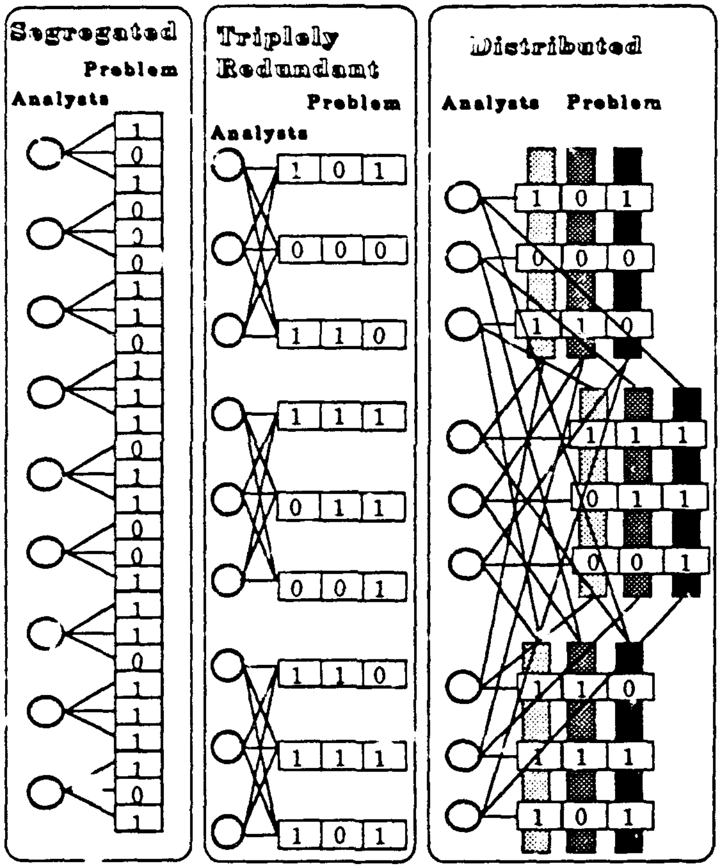


Figure 3: Information Access Structures

2.3. Classification Task

The particular task examined, determining whether there are more 1's than 0's in a binary word of length N, is a very general task involving elements of both pattern matching and determining statistical relationships. In this paper, the organization is modeled as facing the same level of task complexity regardless of whether it is faced by normal operating conditions or crisis

conditions. In this paper, the level of task complexity examined is $N = 27$.[2] Thus, the number of different problems that the organization might see is 2^{27}.

Each decision period the organization is faced with a particular problem. Such a problem is divisible into a set of subproblems, each of which is a portion of the word. Each analyst is given a single subproblem. The size of subproblems and the degree of overlap in who knows what depends on the level of redundancy as defined by the information access structure. Given a subproblem each analyst must decide — yes ("I think there are more 1's than 0's in the full problem" represented by a 1) or no ("I think there are more 0's than 1's in the full problem" represented by a 0). Thus, each decision maker is making a recommendation for what he or she thinks the final decision should be. The individual decision maker by passing on a 1/0 decision rather than the number of 1's has compressed information; hence, there is information loss. And, the degree of information loss is higher the more complex the task.

Problem solution requires integrating the decisions made by the analysts. For each problem there is a decision provided by the organization (the final decision) and a correct decision. The final decision provided by the organization is, for either the centralized or the dual command hierarchy, the decision made by the CEO and is a "1" if the CEO decides there are more 1's than 0's in the problem, and a "0" if the CEO decides there are more 0's than 1's in the problem. For the team, the final decision is the majority vote made by the analysts — "1" if more analysts think there are more 1's or "0" if more analysts think there are more 0's. For both the hierarchy and the team the true answer is a "1" if there really are more 1's than 0's in the problem and "0" if there really are more 0's than 1's. For the problems examined, the word size is odd (27) and there is always a correct decision.

2.4. Decision Procedure and Learning

All DMUs, regardless of position (analyst, AEO, or CEO), learn from experience. Each DMU keeps a cumulative record of the subproblems that it receives, its decisions, and the true answer. For each DMU each subproblem that it sees falls into a particular class. A class is a particular pattern of 1's and 0's, such as 010. The complexity of the subproblem seen by the DMU is defined by the size of the subproblem (i.e. number of bits of information he or she must analyze). The complexity of the subproblem faced by the DMU depends on his or her position in the organizational structure and the coordination scheme used by the organization (see table 1). For example, in a centralized hierarchy with a segregated access structure each DMU sees the same number of positions or bits, three, and so have $2^3 = 8$ classes of subproblems.

[2]In determining what level of task complexity to examine two requirements were taken into account. First, in order to guarantee that there is a correct decision the number of bits in the full problem must be odd. Second, it must be possible to divide the problem such that, with the same number of analysts, different levels of information redundancy can be explored given that there are 9 analysts. When there is no redundancy and 9 analysts the possible choices of task complexity are odd multiples of 9 (9, 27, 45, 63, ...). When redundancy is admitted the task complexity must be greater than 9. Thus, 27 is the simplest case that meets these criteria.

Table 1: Complexity of SubProblem Faced by Various DMUs

Position	Access Structure Segregated	Triplely Redundant	Distributed
Centralized Hierarchy			
analyst	3	9	9
AEO	3	3	3
CEO	3	3	3
Dual Command Hierarchy			
analyst	3	9	9
AEO	5	5	5
CEO	3	3	3
Team			
analyst	3	9	9

As the DMU encounters subproblems it builds up, for each class of subproblems, an expectation as to whether the true decision when it sees a problem in that class is a 0 or a 1. The expectation that the answer is a 0 is defined as the proportion of times in this DMU's experience that, given this class of problems, the correct decision was a 0. The expectation that the answer is a 1 is defined as the proportion of times in this DMU's experience that, given this class of problems, the correct decision was a 1. When the DMU is faced with a subproblem, the DMU uses this experiential information to make a decision using the following procedure:

1. Determine what class the problem is in.
2. If the expectation of a 0 is greater than the expectation of a 1, return 0 as the decision.
3. If the expectation of a 0 is less than the expectation of a 1, return 1 as the decision.
4. If the expectation of a 0 is equal to the expectation of a 1, return either a 0 or a 1 as the decision with equal likelihood.

By using this decision and feedback procedure the DMUs learn to match incoming information to possible decisions in much the same way that parallel distributed processing systems learn to match particular patterns to particular outputs (Rumelhart, 1986; McClelland, 1986). The proposed procedure is in effect weighting each input separately. As such, the learning procedure defined guarantees that the decision maker will come to attend more to that incoming information that "will match" the correct response.

Each DMU (regardless of position in the organization) will initially have no experience to draw on and so will randomly respond with a 1 or 0 to each problem. The organization will thus initially have a 50/50 chance of making a correct decision. Eventually, each analyst will learn to be a "majority classifier" for the type of task and organizational structures examined. That is, each

analyst will learn to simply return a 1 if the majority of the inputs it receives are 1's and a 0 if the majority of the inputs it receives are 0's. In the hierarchical structures upper-level managers will learn to attend most to those analysts who have a history of producing correct decisions. As will be discussed in the results section, this adaptive behavior on the part of managers affects which types of tasks are more suited to hierarchies than to teams.

2.5. Crisis

In this paper, a crisis is characterized as a period of limited duration during which there are one or more communication breakdowns or the value of incoming information is suspect. In effect then, during periods of crisis the organization is seen to be facing the type of problems for which it has been trained but subject to severe operational problems. Only organizations which are fully trained are examined which is to say that each organization examined has faced so many problems (100,000) that each DMU has had experienced with multiple examples of each of the subproblems he or she might face. In addition, all crises examined are of equal length (100 decision periods). The length of the training period relative to the length of the crisis is such that, although the individual DMUs will continue to learn during the crisis, what they learn will have little impact on their performance.

2.5.1. Communication Breakdowns

A communication breakdown is characterized by one or more of the DMUs within the organization becoming effectively "unavailable" — that is, unable to participate in the organization's decision making process — for a period of time. Communication breakdowns are characterized by why the breakdown occurs (type), where the breakdown occurs (location), the duration of the breakdown (duration), and the severity of breakdowns (severity). In order to ease comparison of communication breakdowns and information errors with different characteristics the crisis period is divided into a sequence of sub-periods during each of which one or more DMUs may be unavailable or are faced with information errors. A communication breakdown prevents the passage of both decisions and feedback.

<u>Type:</u> The type of breakdown depends on why a DMU becomes unavailable. A DMU may become completely unavailable because a communication channel breaks or because the DMU its-self can not communicate. For the centralized hierarchy and the team these two types of breakdowns are indistinguishable from an information flow standpoint. In the dual command hierarchy, the presence of multiple channels from/to analysts, these two types of breakdowns may effect different behaviors.

<u>Location:</u> The actual location of the breakdown depends on the type of breakdown. When it is the communication channel that breaks the breakdown can occur between analysts and AEOs or between AEOs and CEOs. When it is the DMU that becomes unavailable the breakdown can occur at either the analyst, AEO, or CEO level. Since a communication breakdown at the CEO level, in this model, completely debilitates the organization such breakdowns will not be analyzed.

Otherwise, we refer to the break down as occurring at the low level (analyst-AEO channels or analysts become unavailable) or the medium level (AEO-CEO channels or AEOs become unavailable). In the team, the only breakdowns that occur are when the analysts become unavailable.

Duration: The duration of the communication breakdown is modeled as the number of decision periods during which the DMU or the communication channel is unavailable. Communication breakdowns of three different durations are examined: (1) short — 10 decision periods, (2) moderate — 20 decision periods and (3) long — 50 decision periods.

Severity: The severity of the communication breakdown is modeled as the number of breakdowns that occur at once. Three different severities considered are: (1) low — 1 breakdown at a time, (2) medium — 2 breakdowns at a time, and (3) high — 3 breakdowns at a time. Note, if we consider the unavailability of DMUs then we are looking at organizations where during crisis one ninth to one third of the organization is disabled at any given moment.

2.5.2. Incoming Information

Another type of operational difficulty which can characterize a crisis is the presence of less accurate information. For the managers, AEOs and CEOs, this occurs automatically when there are personnel or channel breakdowns resulting in information becoming unavailable to them. In addition, the organization can face less accurate information if some of the analysts simply do not have access to current or correct information. Such errors in incoming information is like another type of communication breakdown. In this paper, such information errors are modeled as having a duration and severity just as other forms of communication breakdowns. If an information error occurs then the analysts that are compromised are modeled as having access to incorrect information (their bits are drawn from a different word than that which the other analysts are examining).

3. Measuring Performance and Performance Degradation

Given this decision making process and these structures we can now begin to address the question *"Which structure performs the best during crisis given a particular level of training?"*. First, however, a procedure for measuring organizational performance is required (see figure 4). One measure is the number of "correct" decisions (Carley, 1990b; Carley, mingb; Carley, minga). Specifically, organizational performance is measured as the number of correct decisions that are made during a particular decision window and then estimated using a Monte Carlo approach.

Since organizations are engaged in quasi-repetitive integrated decision making tasks they are learning. In figure 4 the dark line indicates the performance of a typical organization overtime. Periods of crisis are marked by triangles. If a crisis occurs before an organization is fully trained the rate of learning may be slowed down (dark line versus dotted line). If a crisis occurs after an organization is fully trained the performance may be decreased. In both cases, the impact of crisis is measured in terms of how much it degrades performance from performance under normal operating conditions.

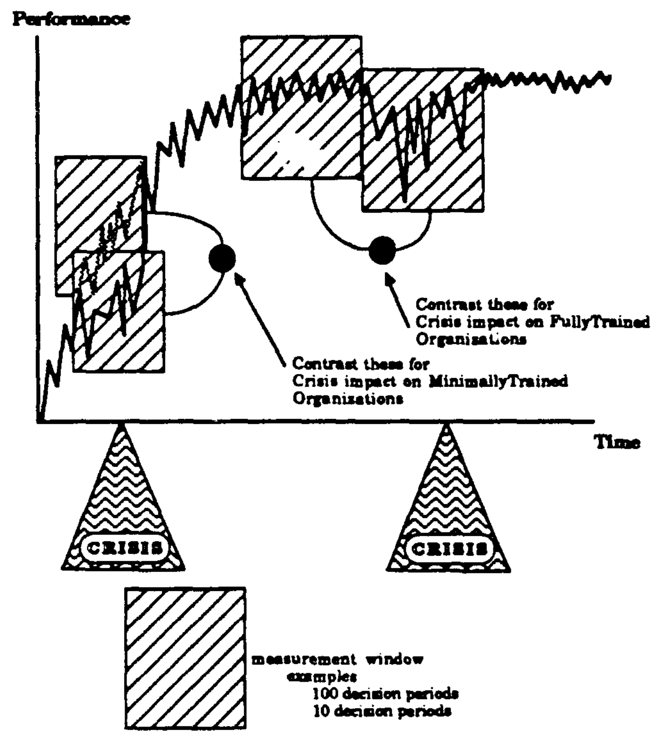


Figure 4: Examining Organizational Performance During Crisis

Monte-Carlo simulation is used to examine how the performance of an adaptive organization, composed of individual decision makers who are continually learning, changes during crisis and whether such an organization can recover from crisis. In the foregoing discussion two parameters — organizational structure (centralized hierarchy, dual command hierarchy, team), and information access structure (segregated, distributed, complete) — were defined to characterize the coordination structure of the organization. Thus there are 9 coordination structures. Similarly, six parameters were defined to characterize crises: duration (short, moderate, long), type of communication breakdowns (analyst, channel), length of communication breakdowns (short, moderate, long), location of communication breakdowns (low, medium), severity of communication breakdowns (low, medium, high), and characteristic of incoming information (accurate, inaccurate). Using these parameters, a variety of crisis scenarios can be constructed.

Each type of organization, given a particular crisis scenario, is simulated 200 times (200 runs). This corresponds to examining 200 different organizations of this type. Each organization is also simulated both to full trained or peak performance mode and minimally trained mode. To become fully trained the organization is simulated for 100,000 decision periods (hence it is faced with a sequence of 100,000 problems). Thus, the organization can be viewed as a fully trained organization; that is, each analyst will have seen several examples of each class of subproblem. In contrast, the

minimally trained organization is simulated for only 100 decision periods. In this case, each analyst may not have seen even one example of each class of subproblems. For the minimally trained organization when crisis occurs, the whole situation may be new. Thus the organization is facing more than just communication breakdowns. The random sequences for communication breakdowns are repeated for each organizational type in order to contrast different organizations faced with the same crisis. The random sequences for communication breakdowns are not repeated across the 200 repeated organizations in order to prevent bias from a particular random sequence choice.

For each organizational type, for both the untrained and the trained level, performance is measured as follows. To determine the impact of crisis on performance, an ensemble measure of performance in a 100 decision period window at three different time periods, relative to the crisis, will be calculated. These three time periods are: (1) performance under normal operating conditions (100 decision periods prior to onset of crisis), (2) performance under crisis conditions (the 100 decision periods during which crisis is occurring), and (3) performance after crisis recovery (100 decision periods at the end of the crisis recovery period). This is illustrated in figure 5. The organization's performance during this 100 decision period window is measured as the percentage of correct decisions made by all 200 organizations with that coordination structure during these 100 decision periods. A correct decision occurs if the organization's final decision matches the true answer. Since the percentage of correct decisions, denoted by p, is based on the sum of 20,000 binary decisions the standard deviation of these measures can be determined as — $((p\,(1-p))/20000\,)^{.5} \times 100$ - for which the maximum value .35% occurs when p is 50%

The dark line indicates the performance of a typical organization overtime. The point at which the crisis begins is marked with an A. The point at which the crisis ends and recovery begins is marked with a B. And the point at which recovery is measured is marked with a C. For all of the organizations examined A equals 100,000; the crisis duration is B-A is 100; and recovery, C-B is 100 decision periods. It is the ensemble average during the 100 decision period window immediately prior to A,B, and C that is used as the measure of pre-crisis, crisis, and recovery performance.

4. Performance Under Normal Operating Conditions

In order to understand the impact of crisis on organizational performance we need to first examine the relative performance of organizations with different coordination structures under normal operating conditions. Under normal operating conditions, provided there is no turnover in personnel, eventually, the organization will learn to make the correct decision at some theoretically optimum level (Carley, mingb). This is the level at which the fully trained organization operates. This level is dependent, first and foremost, on the type of task and only after that on the number of analysts in the organization, the level of task complexity, and the information access structure. For the non-decomposable task examined in this paper the theoretical optimum levels may be below 100%. Thus, although experiential learning may lead to improved performance and greater accuracy, it will rarely lead to perfect performance.

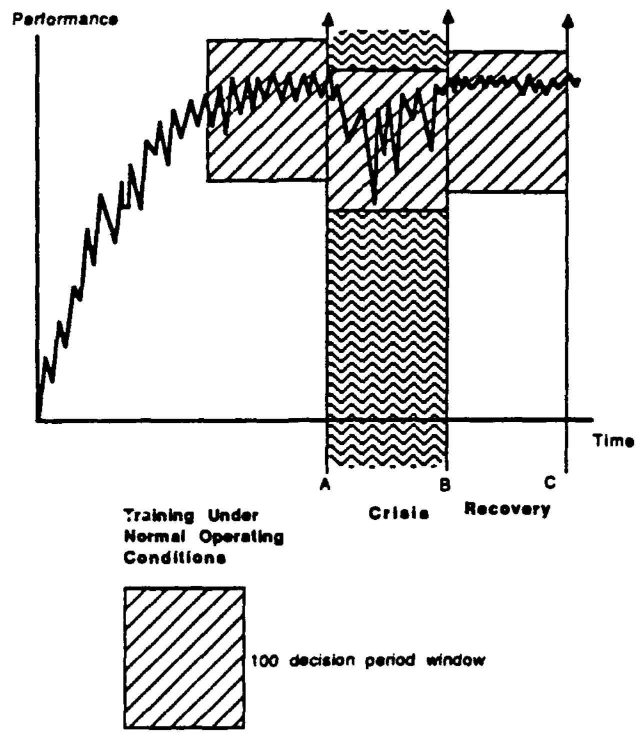


Figure 5: Points at Which Organizational Performance is Measured

There are two reasons why organizations facing non-decomposable tasks face less than perfect performance limits. The first reason is that for non-decomposable tasks, tasks which are complex enough to require information reduction in order to reach a solution result in pertinent information being lost.[3] The second reason, is that the process of channeling and combining information, as happens when information moves from analysts to AEOs to the CEO in a hierarchy, although reducing the complexity of the problem facing each manager, results in yet more information loss. Information loss, whether due to the task being non-decomposable or due to the organizational structures, lowers the theoretical optimum.

The relative performance of the different types of organizations in which the personnel are fully trained are displayed in figure 6. This plot shows the performance level for organizations under normal operating conditions as a function of the organizational structure and access structure. This surface was generated using a 3-D negative exponential interpolation. First, we see that there is a significant access effect; that is, distributed access is better than triplely redundant access which in turn is better than segregated access. Organizations with segregated access structures are the

[3]Only when the task complexity is 9 and the access structure is segregated, and so each analyst sees only one bit of information, is no information lost when the analyst passes on his or her decision. In this paper, however, the task complexity is 27. Thus, regardless of the type of access structure the organizations examined herein suffer information loss.

worse performers because analysts know less of the total problem and so have lower resolution in guessing the true answer.[4] In addition, performance can be improved not only by greater information sharing, as happens in the case of both the triplely redundant and the distributed access structures, but also by carefully arranging who knows what information. Blocking information, such that a group of DMUs see identical information (while it clearly promotes consensus among that group, a consensus that allows them to form a coalition) is less beneficial to the organization than distributing that same information across a wider group. The distributed access structure promotes the highest performance because not only do the various analysts know more, but the organization as a whole gains better resolution on a problem if each piece of information is examined from multiple perspectives (i.e. in conjunction with different sets of other information). Second, we see that there is a structural effect; that is, teams generally outperform hierarchies. Teams outperform hierarchies because there is less information loss due to channeling information up through the organizational structure. There is also an interaction between access and structure such that when access is distributed teams outperform centralized hierarchies which in turn outperform dual command hierarchies, but when a triplely redundant access structure is used the performance of all structures is almost identical, and when a segregated access structure is used dual command hierarchies exhibit a slight improvement over centralized hierarchies.

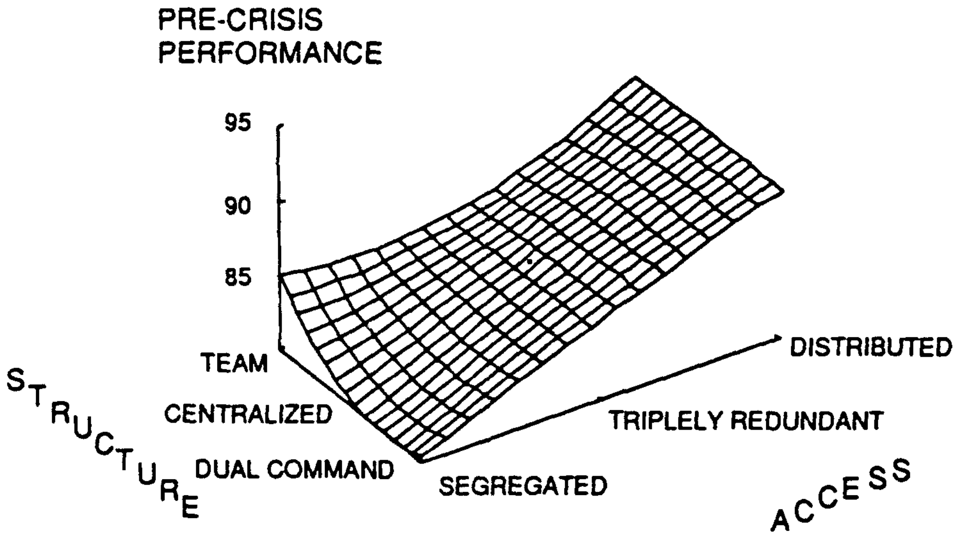


Figure 6: Under Normal Operating Conditions Distributed Teams Perform the Best

Were the organization not fully trained these results would vary in the following systematic fashion. First, the overall level of performance would be lower. Second, teams learn faster than hierarchies and so exhibit in a minimally trained situation higher performance. Third, organizations with segregated access structures learn faster than do organizations with other structures consequently they also exhibit higher performance in the minimally trained situation.

[4]In another study (Carley, 1990b) it was found that information sharing did not always improve performance, particularly if one was concerned with the rate of learning or performance after so many time steps rather than performance in a fully trained organization as was examined in this paper.

5. When Crises Occur

The first thing to note about crises in the fully trained organization is that, regardless of the type of organization or the specific features of a crisis, the crisis degrades performance (see figure 7). But after the crisis the organization returns to its pre-crisis performance level or sometimes does even a little better. The correlation between pre- and post-crisis behavior is 0.996. Post-crisis performance improvements occur because we are dealing with adaptive organizations who continue to learn even during crises and because during the crisis they are doing the task for which they are trained. In this figure performance level increases as one moves from left to right. Each of the lines crossing the three periods represents the average behavior for all organizations with that coordination structure. Within each of the access groups, the organizations are (going from left to right) the centralized hierarchy, the dual command structure,

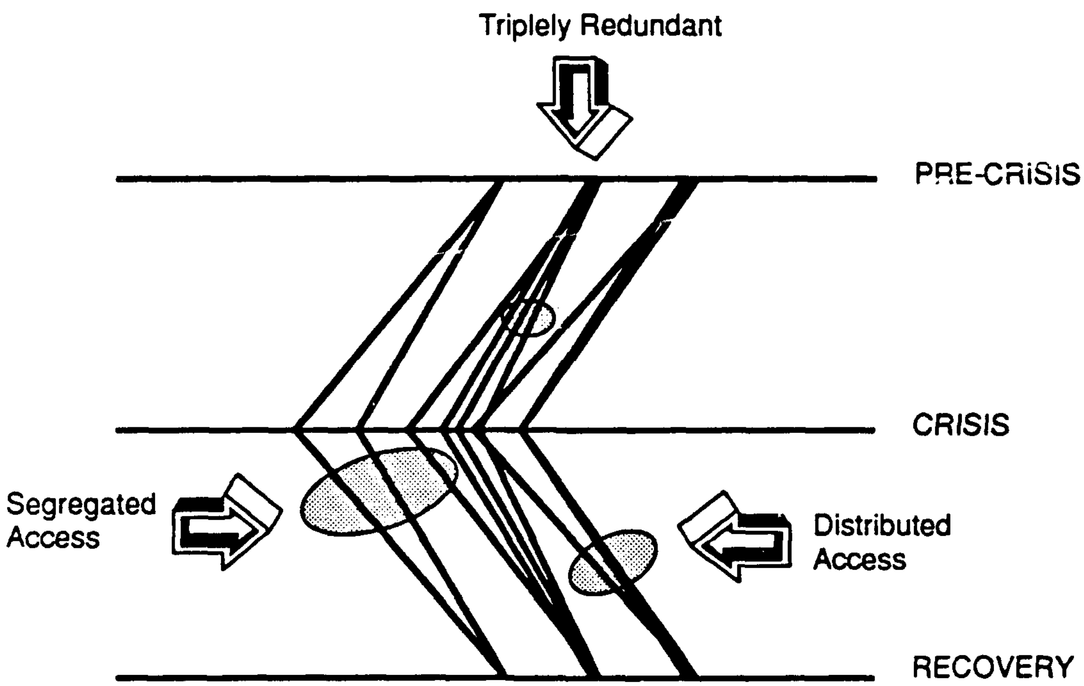


Figure 7: Crises Temporarily Degrade Organizational Performance

and the team.

In marked contrast, in the minimally trained organization, performance improves during crisis (see figure 8). The organizations examined herein are continually changing their performance as their personnel learn. Each experience tends to improve performance. In the fully trained organization the personnel although capable of learning have little left to learn. Consequently, all we see during a crisis is a degradation in performance. Whereas in the minimally trained organization, the personnel have so much left to learn that the organization continues to improve despite the impairment due to crisis. Were there no crisis, the organization would probably learn faster, however, this is a point for future investigation.

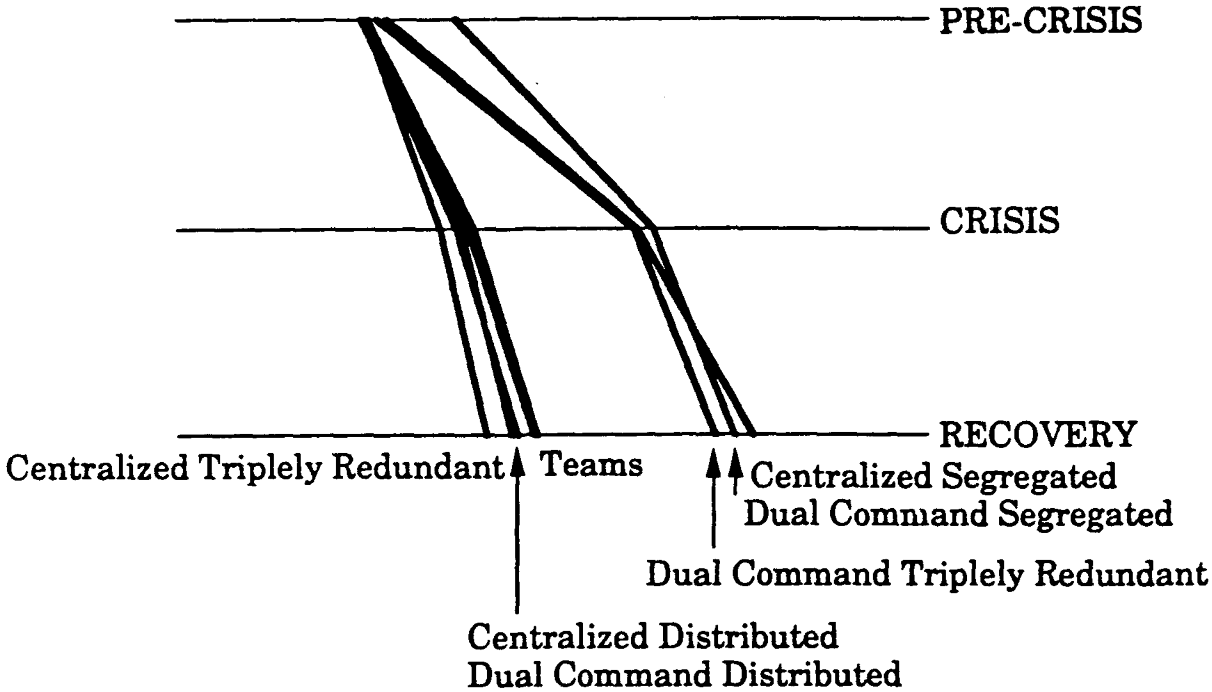


Figure 8: Minimally Trained Organizations Can Learn During Crises

While organizational performance is affected by crisis, not all organizations are equally affected. For example, for fully trained organizations, centralized hierarchies are much more affected by crises than are either dual command hierarchies or teams. And organizations with a distributed access structure are more affected than are organizations with a segregated access structure which are more affected than organizations with a triplely redundant access structure. Despite this variation in resiliency to crisis, fully trained organizations still show the same basic relative performance during crisis as they do under normal operating conditions. This is not the case for minimally trained organizations. Training has a major effect on performance (see figure 9).

Now let us contrast performance level under crisis with optimal performance. As cane be seen in figure 10 the optimal configuration depends on the situation. If the organization is fully trained and there is no crisis then the best structure is a team with a distributed access structure, but when a crisis strikes the best structure is the hierarchy with a distributed structure. In contrast if the team is not fully trained and the crisis occurs then the best structure is a hierarchy with a segregated access structure.

Another aspect of performance is resiliency. That is, how much is performance degraded from what it would be under fully-trained normal operating conditions. For example, while a dual command hierarchy with a distributed access scheme is only mildly affected by crisis when the organization is fully trained it is one of the most affected schemes when there is only minimal

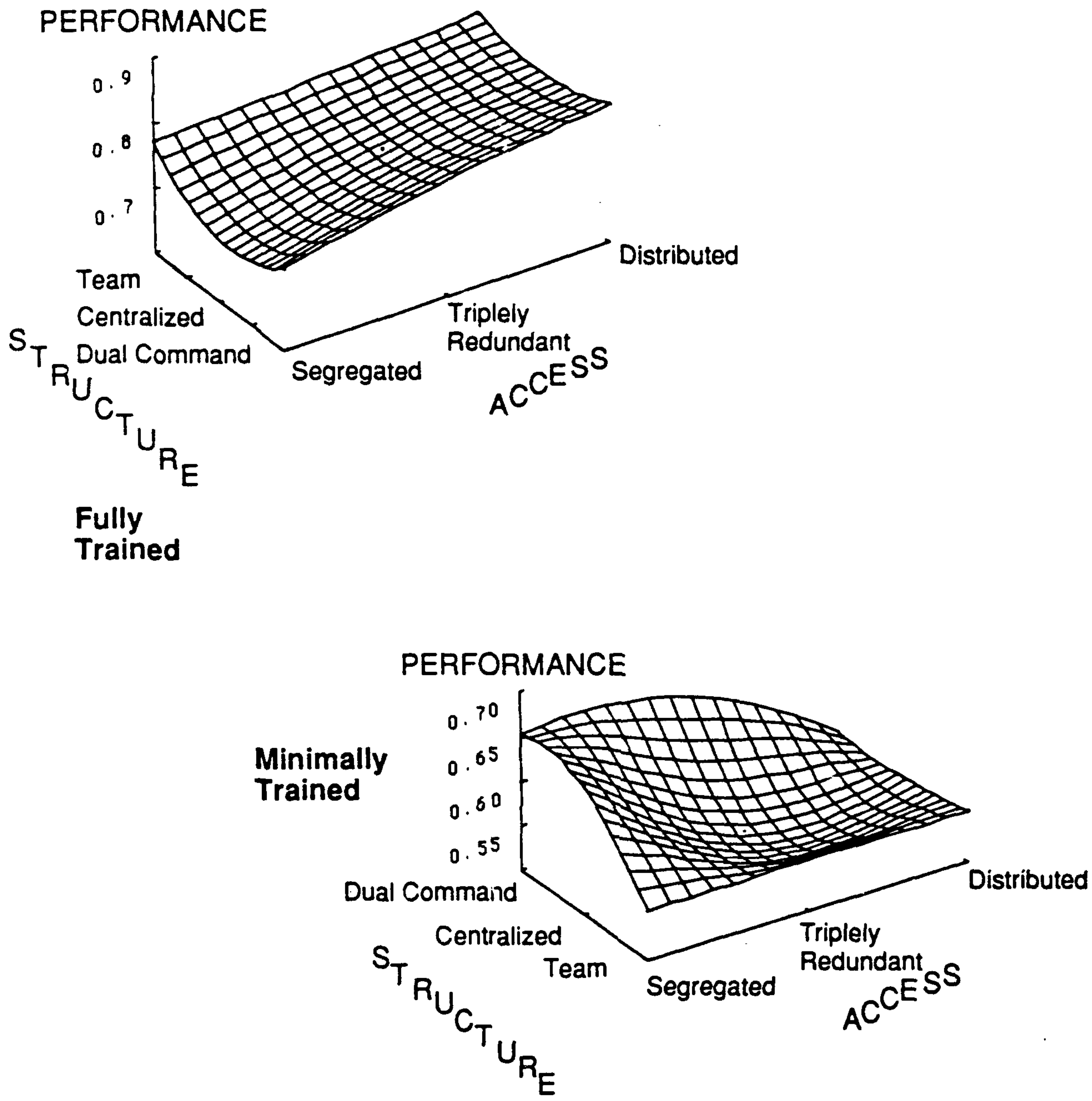


Figure 9: Different Organizations Perform Differently Under Crisis

training. These two graphs show the degradation in performance due to crisis for the highly trained (top) and minimally trained (bottom) organization for organizations with different structures and access schemes. Performance degradation is measured as optimal performance (performance under normal operating conditions for the fully trained organization) minus performance during crisis.

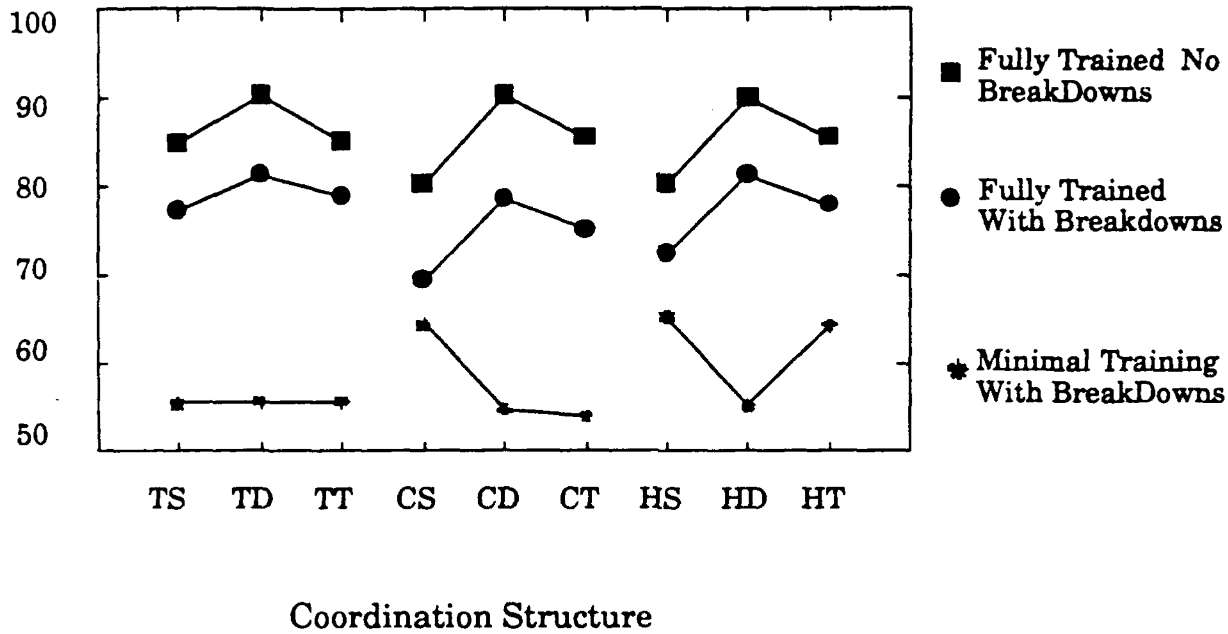


Figure 10: Optimal Configuration Depends on Situation

5.1. What Type of Crisis is Most Debilitating?

Of the types of crises examined, those in which the incoming information is erroneous generally degrade organizational performance more than those where either DMUs become unavailable or communication channels breakdown (see figure 12). Only when the information access structure is segregated is it worse to have channel or DMUs unavailable than to have erroneous incoming information. This result follows from the fact that when there is redundant access to incoming information, if the information is erroneous there are more DMUs who will be mislead by it. But, this same redundancy enables the organization to maintain higher levels of performance even when DMUs become unavailable and communication channels breakdown.

For teams and centralized hierarchies channels breaking down and DMUs becoming unavailable are functionally identical events. Only in the dual command hierarchy do the two events produce different results and in this case channel breakdowns are the least debilitating. For the dual command hierarchies performance degrades more when analysts become unavailable than when channels breakdown as even if a channel breaks there are alternate routes by which the information can move up the hierarchy but, as in a centralized hierarchy or team when the DMU becomes unavailable information may be lost.

In a fully-trained organization a crises in which the information acquired by the analysts is erroneous is the most debilitating; whereas, when the organization is less fully-trained having decision makers become unavailable — either because they themselves are affected or because the

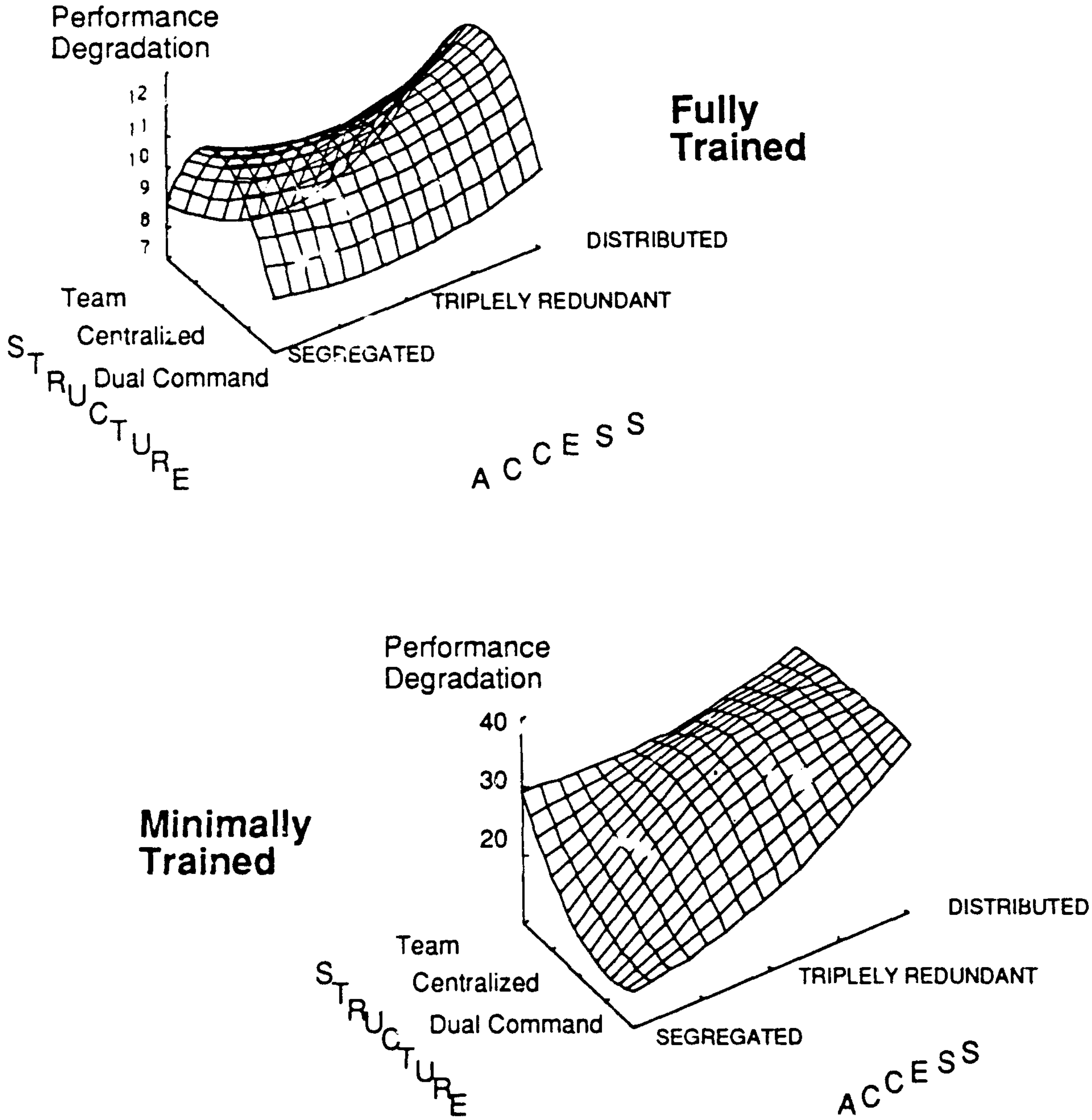


Figure 11: Crisis Degrades Different Organizations Differently

lines of communication have been broken — is more damaging to organizational performance. Within fully-trained organizations erroneous information is generally, but not always, the most debilitating type of crisis (see figure 13). When the organization has a segregated information access structure having a communication breakdown can be as or more debilitating.

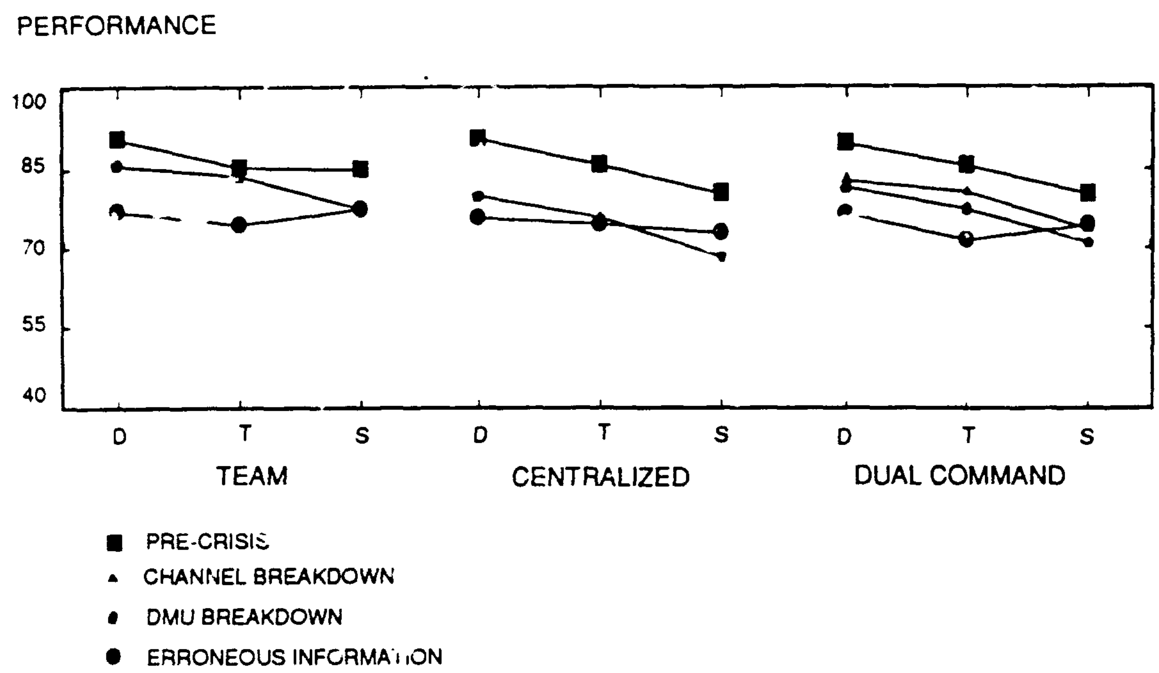


Figure 12: Erroneous Information is Generally More Debilitating than Breakdowns

For teams and centralized hierarchies channel and DMU breakdowns are functionally equivalent. Each dot is the average performance value for all organizations in that category.

5.2. As the Duration of the Breakdown Increases

For the various crises examined different DMUs are incapacitated, either through a breakdown or through errors in incoming information, for various amounts of time. For the organizations examined the length of this incapacitation has little impact on performance (see figure 14). The reason for this is that all organizations are fully trained thus local adaptation during the crisis there is little impact on performance.

5.3 As the Breakdown Increases in Severity

Regardless of the level of training the more severe the crisis the less able the organization is to make correct decisions (see figure 15). Fully-trained organizations, because they begin by operating at peak performance suffer greater degradation due to crisis than due minimally-trained organizations. Thus, a minimally trained organization may feel that the severity of the crisis has no impact on performance. This is true regardless of the organizational coordination scheme or the type of crisis.

Severity increases as the number of DMUs whose performance is compromised (whether due to

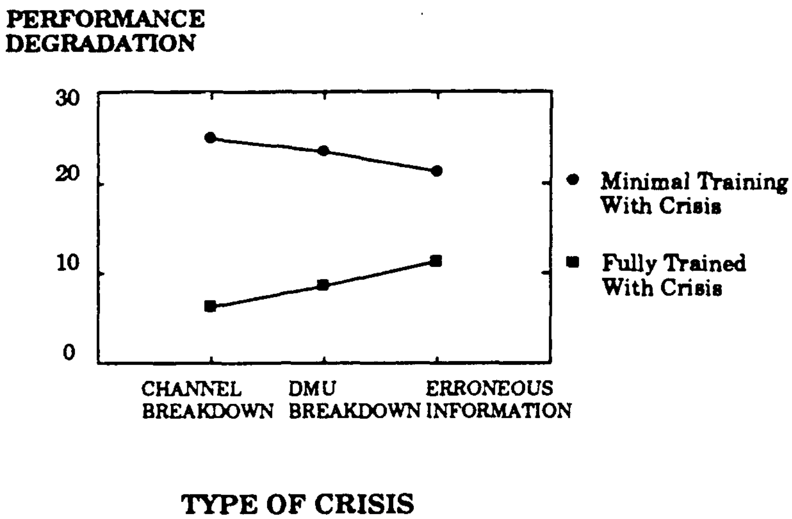


Figure 13: Training and Type of Crisis

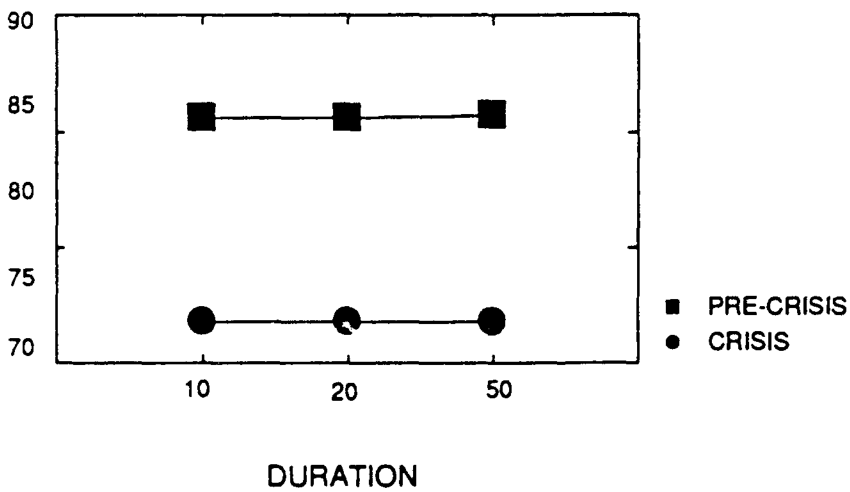


Figure 14: Duration of Breakdowns Does Not Affect Performance

For a fully trained organization the length of the different communication breakdowns (whether in channel, DMU unavailability, or erroneous incoming information) does not affect organizational performance. Each dot is the average performance value for all organizations in that category.

unavailability, channel breakdown, or erroneous incoming information) at the same time increases. Going from left to right, the severity index (1,2,3) indicates the number of "primary sights" that

simultaneously breakdown. For DMU breakdowns this is the number of DMUs that are not communicating. For channel breakdowns this is the number of channels that can not be used. For erroneous incoming information this is the number of analysts who are receiving incorrect new information. Each dot is the average performance value for all organizations in that category.

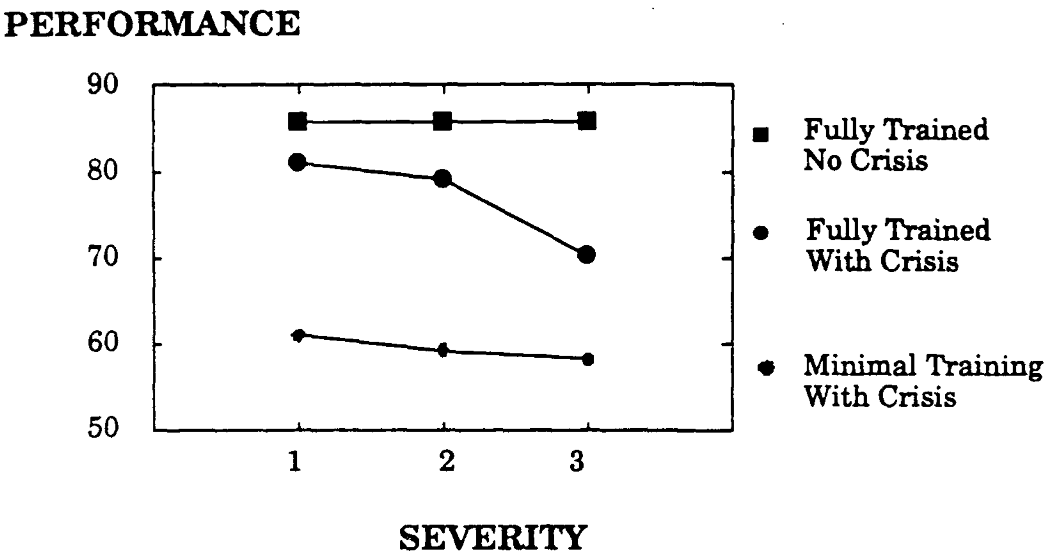


Figure 15: Increasing Severity Decreases Performance

6. Cost and Performance

Performance, of course, is only part of the story. Coordination does not occur without costs. Two such costs are information processing and communication. Information processing costs can be thought of as increasing as individual decision makers increase the amount of information that they must deal with. Such costs should thus be proportional to the amount of information that each DMU must deal with. Communication costs can be thought of as the cost of installing lines of communication (e.g., new telephone lines or fax's) and the associated time cost to personnel in having to use these channels. Table 2

High cost does not guarantee high performance. In figure 16 we see that whether absolute performance or degradation is examined cost is unrelated to performance. In this figure, the greater the circle the greater the cost of running that type of organization.

7. Discussion

The notion of crisis used herein, a period of limited duration during which there are one or more communication breakdowns or the value of incoming information is suspect, is a somewhat stereotypic view of crisis that does not capture many of the nuances and peculiarities that make such periods — crises. Other aspects of crises include a rapid increase in the rate of incoming

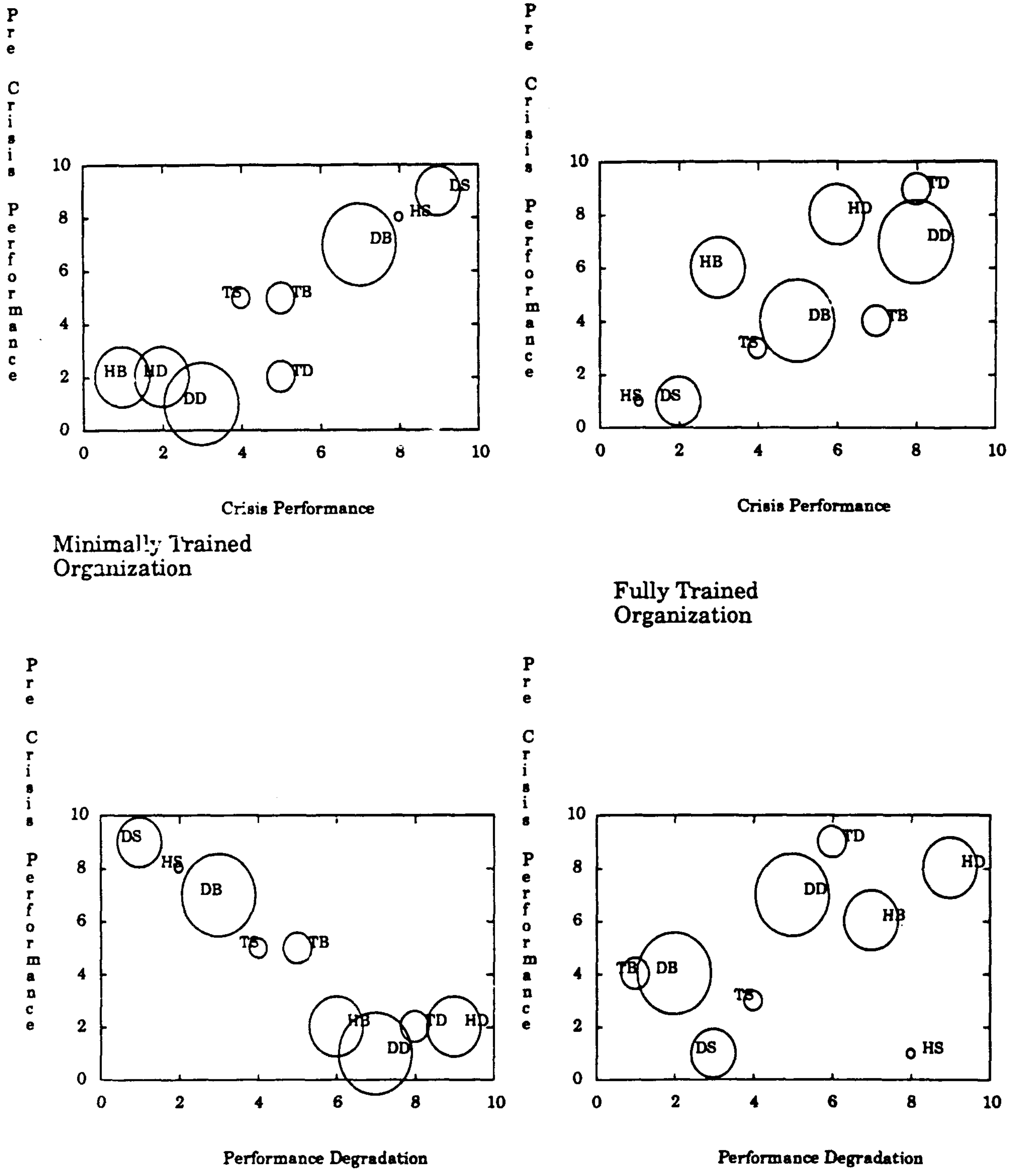
Table 2: Coordination Scheme and Cost

Coordination Scheme	Information Processing		Communication	
	Cost	Rank	Cost	Rank
Centralized Hierarchy				
Segregated	39	48	12	2
Triplely Redundant	57	2	12	2
Distributed	57	2	12	2
Dual Command Hierarchy				
Segregated	45	3	18	1
Triplely Redundant	63	1	18	1
Distributed	63	1	18	1
Team				
Segregated	27	5	9	3
Triplely Redundant	45	3	9	3
Distributed	45	3	9	3

information, a rapid increase in the rate at which decisions must be made, a sense of uniqueness, and the potential creation of a new command structure. And of course, all of these crisis features could occur at the same time and may have synergistic effects.

The first two of these aspects, increase in the rate of incoming information and required decisions, indicate the importance of timing in analyzing organizational behavior during crises. In the model proposed herein, there is no absolute sense of time; rather, time is divided into a series of decision periods. Were measures of absolute time incorporated, issues such as delay due to communicating decisions and feedback through different channels could be examined. Such an examination, might provide a very different view of what organizational structure is the most effective during crisis. For example, (Carley, 1988) found that distributed structures, as opposed to hierarchies, could respond more quickly to crises but were more likely to make mistakes.

For many organizations, facing a crisis means facing a situation for which the organization is not prepared, or with which there has been little actual experience. Crises are, after all, quite rare. In such cases, experience gained under normal operating conditions may not be transferable thus resulting in an organization whose personnel have *no* experience. This study began to address this issue by comparing the behavior of the minimally and the fully trained organization. This presumes, however, that the crisis problem is the same type of problem that the organization has dealt with — but just an unfamiliar one. Similarly, when a crisis occurs some organization create completely new organizational structures to deal with that crisis. For example, when a natural disaster occurs the Red Cross in conjunction with local service groups constructs a special temporary organization to cope with that disaster. In such new temporary organizational structures the individuals have never worked together before let alone on this particular type of crisis. Whether due to novelty of the task



Minimally Trained Organization

Fully Trained Organization

Minimally Trained Organization

Fully Trained Organization

Figure 16: Cost Unrelated to Performance

(crisis) or the organizational structure the group of individuals who must make decisions and

integrate their behavior in an attempt to cope with the crisis come into the situation with either no experience, or different levels of experience, or inappropriate experience not to mentions differences in norms and procedures for behaving. In this paper, the members of the organization all began the crisis with not only the same level and type of experience, but they were fully trained. And it was from such a highly prepared state that the ability of the organization to cope with crisis was determined. As a consequence what was learned during the crisis had little effect on performance and so post crisis performance was almost identical to pre crisis performance and the length ot the crisis and the duration of the communication breakdowns and other incapacitations are irrelevant to behavior. Although not examined herein, the proposed model could be used to determine which type of organizational structure can best cope with crises when the personnel are less optimally prepared. Such an analysis might lead to different conclusions than those drawn herein. In particular, such an examination would develop our understanding or learning and adaptive learning during the crisis and so would allow an examination of questions such as *do crises promote learning the wrong thing*.

Additionally, individual and organizational behavior have also been over simplified. Many of these simplifications have been discussed elsewhere (Carley, mingb) and need not be repeated here. Given the focus on crisis attention will now be turned to just those simplifications of individuals and organizations that are particularly important when studying crisis.

Individuals within the organization are modeled as perfect historians engaged in experiential based decision making. Admittedly, this is an oversimplification of actual human decision making behavior; these "individuals", despite being intendedly adaptive and imperfect statisticians, do not exhibit all of the cognitive limitations known to affect individual decision making behavior, particularly under stress. Yet, under stress individuals tend to make more mistakes, take longer to solve problems, are less able to solve problems, and satisfice. Whereas, in the proposed model, individuals exhibit the same problem solving and information processing skills during crisis as they do under normal operating conditions. Thus, future work should consider the additional impact of such compromised to individual cognition that might result during crises. A second aspect here is that individuals as perfect historians rely as much on information that they received a year ago as that which they receive today. Yet, there are saliency affects such that individuals attend more to the most recent information. Were the DMUs to attend more to recent information the value of training might be decreased with the upshot that the organization is even more affected by crisis than suggested in this study. Factors such as stress and salience, should they be taken into account, might effect different relative performance among the types of organizations examined.

Organizations are treated as having relatively fixed structures; that is, the number of DMUs is fixed, there is no turnover, even if DMUs become incapacitated these same analysts later re-emerge and take over their former positions, and so on. Yet, during crises personnel may continue to turnover. For example, during a crisis the organization may not know that a communication breakdown is temporary and may promote someone to fill the gap or in an effort to "right the wrong" personnel may be fired or transferred. Such turnover, unlike the temporary communication

breakdowns that were examined in this paper, creates an organization in which the personnel may come into the crisis with different levels and types of experience. Further, since turnover tends to make organizations learn slower and less (Carley, mingb) then organizations who must cope with turnover may be less affected by crisis than those examined herein where there was no turnover.

Despite its limitations, the proposed model does capture many of the features of crisis and organizational behavior. These include information loss, communication breakdowns, information sharing, limited rationality on the part of decision makers, and organizational structure. With some modification, the proposed model can serve as a framework to look at many of the issues just discussed. As an example, we might consider implementing turnover with different ratios of executive to staff turnover, or even different types of turnover such as a performance based or a tenure based model of turnover in order to examine whether turnover augments the effect of communication breakdowns organizational performance during crisis. As a final example, this framework could be used to look at the impact of the timeliness and accuracy of feedback on organizational learning and hence performance. In the studies presented in this paper, organizations received prompt accurate feedback. While organizations learn from experience, the feedback that is provided may be incomplete, slow, inaccurate, and subject to interpretation particularly during periods of crisis. Thus, future studies should consider the role of incomplete or slow feedback.

8. Conclusion

A fairly general model of adaptive organizational performance has been proposed and its implications for organizational performance under normal operating conditions and crisis examined. Policy implications follow from the results of this analysis. Several of these bear emphasizing. The first implication is that organizations that use a redundant access structure should not block information (as in the triplely redundant structure) as blocking information while promoting consensus and coalition formation among certain individuals does not promote the multiplicity of perspectives that a more distributed scheme provides. Multiple perspectives, although it may increase the chance of disagreement between individuals, is beneficial to the organization as a whole as it increases overall resolution on the problem. The second implication is that it will generally be more efficacious for the organization to spend more money on getting the information right in the first place than in setting up extra communication channels. Further, within hierarchies, the higher up in the organization the breakdown occurs the more drastic the consequences. Thus, the third implication is that, in a fully trained organization, the organization should spend more of its effort to prevent high level channel breakdowns and high level decision makers from becoming unavailable than to ensure the operation of decision makers further down in the organizational hierarchy. In contrast, in a minimally trained organization communication breakdowns lower in the organization are more devastating. Another point is that fully-trained organizations outperform minimally trained organizations even during crisis consequently this study suggests that all organizations should increase the level of training. And yet another point is that minimally trained organizations

do best during crisis and not when access is segregated whereas in a fully trained organization a distributed access scheme is better. The reason for this, in part, is that for the same size problem a distributed scheme increases the size of the sub-problem faced by the analyst. Consequently, distribution slows the rate of learning. This suggests that when learning is a concern and a distributed access scheme is necessary the organization should work in other ways to simplify the problem at hand.

The final implication has to do with the best organizational design for optimal crisis performance. Every organization faces crises at some point or another. But should organizations structure themselves such that crises when they occur have little effect. This study suggests that all such organizations should take certain measures, but that only some organizations should take others. Let us consider the cost of the different coordination schemes. Redundant access schemes, such as the triplely redundant and the distributed, increase the complexity of the task faced by the analysts which slows the rate of learning but can improve performance in a fully trained organization. Redundant access schemes are costly from an information storage and processing perspective. Redundant channels, such as those that occur in the dual command structure, increase the complexity of the task faced by the DMUs which slows the rate of learning but does not necessarily alter performance in the fully trained organization. Redundant channels are costly from both an information processing and a communication standpoint. For all fully trained organizations having some information redundancy is a good thing; that is, information redundancy improves performance both under normal operating conditions and during crisis. In contrast, in the minimally trained organization information redundancy slows the rate of learning to the extent that performance is compromised both under normal and crisis conditions. As long as the issue is not one of learning, the increase in performance attributable to a redundant structure may offset the increase in information processing and storage costs. In contrast, only organizations, regardless of training, that expect frequent crises may be interested in adding redundant channels as there is little effect on performance under normal operating conditions but a great improvement under crisis conditions. In this case, the increase in communication and information processing costs may not be recoverable.

All of this suggests that one of the best crisis mitigating behaviors is training. But, mis-estimation of the level of training that your organization possesses and planning accordingly can be devastating. The organization that thinks that it is fully trained and organizes itself accordingly — such as with a dual command hierarchy distributed access structure — may actually be in the worst shape if faced with a completely novel situation.

This study suggests that different organizational structures are differentially responsive to crises. And, that there is no one structure that is always the best. Collectively, they suggest that the best structure for crisis depends on whether the organization can train for the crisis. If a crisis is a truly novel situation then the best structure seems to be a small, highly differentiated, team with a flexible personnel movement policy. Even here there is a tradeoff, that is, for maximal efficiency a

non-segregated information access structure seems best but for learning and rapid response a segregated structure seems best. However, if a crisis can be trained for (which is clearly the operating assumption at NORAD) then it seems that the size of the organization is not important. Further, in this case, highly differentiated, dual-command hierarchies with non-segregated information access structures and a flexible personnel movement policy seem to be the structure least affected by crisis.

These results suggest that an organization that assumes that crises can be trained for and so structures itself for optimal performance under these conditions will, when faced with a crisis that is truly novel, be decimated. For example, the dual-command hierarchy with a distributed structure is one of the most optimum organizational configurations for facing crises when the organization is fully trained for such crises but is one of the worst configurations when the crisis is novel. If training is not the answer to effective crisis performance — *what can organizations do?* A possible answer is suggested in some of the recent work by LaPorte (1988). LaPorte found, in his study of air traffic controllers, that the organization actually shifted structures as it moved into and out of crises. Whether such transitions are truly beneficial is a point for future study. Moreover, during crises a variety of factors come into play that have not even been considered here, such as emotional based response, stress, and reduced decision time.

Finally, when the cost of the organizational coordination scheme is taken into account we see that high cost does not guarantee high performance. Thus, there are some costs that, unless the organization expects frequent crises, are probably not worth incurring. One example is increased costs due to installing redundant communication channels.

REFERENCES

Arrow K.J. and Radner R. (1979). Allocation of Resources in Large Teams. *Econometrica, 47*, 361-85.

Bar-Shalom Y. and E. Tse. (1973). Tracking in a Cluttered Environment with Probabilistic Data Association. *Proc. of the Fourth Symposium on Nonlinear Estimation*. UC San Diego, CA.

Burns T. and G. Stalker. (1961). *The Management of Innovation*. London, England: Tavistock.

Carley K.M. (1986). Measuring Efficiency in a Garbage Can Hierarchy. In March J. and R. Weissinger-Baylon (Eds.), *Ambiguity and Command: Organizational Perspectives on Military Decision Making*. Boston, MA: Pitman.

Carley K.M. (1986). Efficiency in a Garbage Can, Implications for Crisis Management. In March J. and R. Weissinger-Baylon (Eds.), *Ambiguity and Command: Organizational Perspectives on Military Decision Making*. Boston, MA: Pitman.

Carley K.M., Lehoczky J., Rajkumar R., Sha L., Tokuda, H., and L. Wang. (1988). Comparing Approaches for Achieving Near Optimal Solutions in a Distributed Decision Making Environment. Working Paper.

Carley K.M. (November 1990). Making the Best Decision: A Model of Organizations Coping with Communication Breakdowns Applied to R&D Funding.

Carley K.M. (January 1990). Coordinating for Success: Trading Information Redundancy for Task Simplicity. *Proceedings of the 23rd Annual Hawaii International Conference on System Sciences*. .

Carley K.M. (forthcoming). Designing Organizational Structures to Cope with Communication Breakdowns: A Simulation Model. *Industrial Crisis Quarterly*, , .

Carley K.M. (forthcoming). Organizational Learning and Personnel Turnover. *Organization Science*, .

Cohen M.D., March J.G. and J.P.Olsen. (March 1972). A Garbage Can Model of Organizational Choice. *Administrative Sciences Quarterly*, *17*(1), 1-25.

Crecine J.P. (1986). Defense Resource Allocation: Garbage Can Analysis of C3 Procurement. In March J.G. and R. Weissinger-Baylon (Eds.), *Ambiguity and Command: Organizational Perspectives on Military Decision Making*. Marshfield, MA: Pitman Publishing Inc.

Davis R. (1980). Report on the Workshop on Distributed Artificial Intelligence. *SIGART Newsletter*, *73*, 43-52.

Davis S. and P. Lawrence. (1977). *Matrix*. Reading, MA: Addison-Wesley.

Durfee E., Lesser V. and D. Corkill. (1985). Increasing coherence in distributed problem solving networks. *Proceedings of the Ninth International Conference on Artificial Intelligence*. .

Gloves T. and J. Ledyard. (1977). Optimal Allocations of Public Goods: A Solution to the Free-Rider Problem. *Econometrica*, *45*, 738-809.

Hassti R., Park B., and R. Weber. (1984). Social Memory. In Wyer R.S. and T.K. Srull (Eds.), *Handbook of Social Cognition*. Hillsdale, NJ: Erlbaum.

Johnson M.K. and L. Hasher. (1987). Human Learning and Memory. *Ann. Rev. of Psychology*, *38*, 631-68.

LaPorte T.R. and P.M. Consolini. (1988). Theoretical and Operational Challenges of 'High Reliability Organizations': Air Traffic Control and Aircraft Carriers.

Lesser V.R. and D. D. Corkill. (1981). Functionally accurate, cooperative distributed systems. *IEEE Transactions on Man, Systems, and Cybernetics*, *SMC-11*(1), 81-96.

Levitt B. and J.G. March. (1988). Organizational Learning. *Annual Review of Sociology, 14*, 319-40.

Lichtenstein S. and B. Fischhoff. (1977). Do those who know more also know more about how much they know? The calibration of probability judgments. *Org. Behavior and Human Performance, 20*, 159-183.

Lindblom C.E. (1959). The "science" of muddling through. *Public Administration Review, 19*, 79-88.

Malone T.W. (1986). *A Formal Model of Organizational Structure and Its Use in Predicting Effects of Information Technology* (Tech. Rep.). MIT: Sloan School of Management,

Malone T.W. (1987). Modeling Coordination in Organizations and Markets. *Management Science, 33*, 1317-1332.

March J.G. and P. Romelaer. (1976). Position and presence in the drift of decisions. In March J.G. and J.P. Olsen (Eds.), *Ambiguity and Choice in Organizations*. Bergen, Norway: Universitetsforlaget.

Marschak J. (1955). Elements for a Theory of Teams. *Management Science, 1*, 127-137.

Masuch M. and P. LaPotin. (1989). Beyond Garbage Cans: An AI Model of Organizational Choice. *Administrative Science Quarterly, 34*, 38-67.

McClelland J., Rumelhart D., et al. (1986). *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*. Cambridge, MA: MIT Press.

Padgett J.F. (1980). Managing Garbage Can Hierarchies. *Administrative Science Quarterly, 25*(4), 583-604.

Padgett J.F. (1980). Bounded rationality in budgetary research. *Am. Pol. Sci. Rev., 74*, 354-372.

Radner R. (1987). Decentralization and Incentives. In Groves T., Radner R., and S. Reiter (Eds.), *Information, Incentives, and Economic Mechanisms: Essays in Honor of Leonid Hurwicz*. Minneapolis, MN: University of Minnesota Press.

Rumelhart D., McClelland J., et al. (1986). *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*. Cambridge, MA: MIT Press.

Smith R. (1980). The Contract Net Protocol: High-Level Communication and Control in a Distributed Problem Solver. *IEEE Trans. on Computers, C-29*(12), 1104-1113.

Steeb R., et. al. (1980). *Distributed intelligence for air fleet control* (Tech. Rep.). The Rand Corporation,

Steinbruner J.D. (1974). *The Cybernetic Theory of Decision Processes*. Princeton, NJ: Princeton University Press.

Strand R.G. (1971). An Efficient Suboptimal Decision Procedure for Associating Sensor Data with Stored Tracks in Real-Time Surveillance Systems. *Proc. IEEE Conf. on Decision and Control*. Miami Beach, FL.

Thorndyke P., McArthur D. and S. Cammarata. (1981). Autopilot: A distributed planner for air fleet control. *Proceedings of the Seventh IJCAI*. Vancouver, B.C. Canada.

Tsitsiklis J.N. and M. Athans. (1984). On the Complexity of Decentralized Decision Making and Detection Problems. *IEEE Transaction on Automatic Control, AC-30*, 440-446.

Tversky A. and D. Kahneman. (1971). The belief in the law of small numbers. *Psychological Bulletin, 76*, 105-110.

Tversky A. and D. Kahneman. (1974). Judgment under uncertainty: heuristics and biases. *Science, 185*, 1124-1131.

Weber M. (1922). Bureaucracy. In Gerth H. and C.W. Mills (Eds.), *Max Weber: Essays in Sociology*. Oxford, England: Oxford University Press.